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TOPOLOGY OPTIMIZATION AND MANUFACTURING ASPECTS FOR HULL STRUCTURE OF WHEELED COMBAT VEHICLE

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Abstract - Light weight design of hull structure chassis of wheeled combat vehicle is quite challenging task considering requirement of lower chassis weight with high stiffness during military operations and cross country mobility aspects. The research work presents structural topology optimization of hull structure of combat vehicle to obtain optimal material distribution within available space pertaining to required stiffness parameters and boundary constraints. Optimal weight of vehicle is computed using density method by defining minimum compliance and volume as objective function of the topology optimization study. Present study highlights problem formulation with solid isotropic material with penalisation (SIMP) optimization technique. Various static and dynamic loading conditions have been considered for optimization of vehicle structure. Based on the output of the optimization study, suitable recommendations have been made for hull structure designer in terms of optimal layout configuration of structural members in the early stage of design.

Keywords - Topology Optimization, Chassis Design, Combat Vehicle, Compliance, Finite Element Analysis.

I. INTRODUCTION

Chassis design of a combat vehicle is challenging task considering the following major requirements of chassis:-

a) To provide support for various subsystems, e.g. power pack, transmission, drivelines, weapon system, crew compartment, etc.
b) To withstand various static and dynamic loads generated due to various terrain conditions and vehicle dynamics
c) To provide protection against ballistic and blast threats.

Combat vehicles have various configurations based on role of the vehicle on battle field e.g. Armoured Fighting Vehicles (AFVs), Armoured personnel Carrier (APC), Recce and support vehicles, etc. combining operational mobility with tactical offensive and defensive capabilities. AFVs can be wheeled or tracked.

Topology optimization is a powerful tool in many areas of design such as structural mechanics, optics and electronics. The field emerged from structural design and so topology optimization applied in this context is also known as structural optimization.

Applying topology optimization to structural design typically includes considering quantities such as weight, stiffness, stresses, displacements, buckling loads and resonant frequencies, with some measure of these defining the objective function and others constraining the system. For other applications aerodynamic performance, conductance, optical performance may be of interest, in which case the underlying state equations are very different to those considered in the structural case.

Topology optimization, also called structural layout optimization, the basic idea is a design method that seeking for the most optimal distributing form structural stiffness in design space or the best way to pass power, in order to achieve optimization of some behaviors or alignment of the structure weight. Topology optimization is the first step in design of structural optimization, followed by shape optimization and size optimization. With maturation and improvement of shape and size optimization design in structure, the topology optimization has been becoming the hotspot and the difficult problem in structural optimization design research field. Because of the topology optimization’s singularity feasible region, its main problem is a big difference between the global optimal solution and local optimal solution. But the application of topology optimization in practical engineering, often due to the numerical instability phenomena which led to the boundary shape optimization that the results are not clear, it is exist the main numerical problem that is checkerboard format, grid-dependent and local maximum or minimum in topology optimization process [1].

An optimization that only allows discrete design variables (void or material) is unfortunately not a realistic alternative when dealing with large numbers of design variables [2]. Because of this, a continuous measure of material existence, ρ, is introduced. Where and 0 is interpreted as void and 1 as solid material. Value in between might be interpreted as a material with a lower density and Young's modulus. The induction of a continuous measure of material presence in an element has been done for computational reason; however, it is still desirable to have discrete design variables (void or material). One way to make the design variable more discrete is to use the SIMP method (Solid Isotropic Material with Penalization) [3].

III. TOPOLOGY OPTIMIZATION FORMULATION

To formulate the structural optimization problem, an objective function, design and state variables needs to be introduced as described in [4]. The objective function (f), represents an objective that could either be maximized or minimized. A typical objective could be the volume or stiffness of a structure. Moreover, some structural design domain and state variables associated to the objective function needs to be defined. The design variables (x) describes the design of the structure, it may represent the geometry. The state variables (y) represents the structural response which can for example be recognized as stress, strain or displacement. Furthermore, the state variables depend on the design variables y(x). The objective function is subjected to the design and state variable constraints to steer the optimization to a sought solution.

$$\begin{cases} \min x & f(x, y(x)) \\ \text{subject to} & \begin{cases} \text{design constraint on } x \\ \text{state constraint on } y(x) \\ \text{equilibrium constraint} \end{cases} \end{cases} \tag{1}$$

A state function g(y) that represents state variables can be introduced, for example displacement in a certain direction. This state function can be incorporated as a constraint to the optimization task, where it is usually formulated such that $g(y) \leq 0$. Consider the case where g(y) is represented by a displacement vector g(u(x)) in a discrete finite element problem. To establish the state function, this requires that nodal displacement is solved for

$$u(x) = K(x)^{-1} f(x) \tag{2}$$

where K is the global stiffness matrix and f is the global load vector. This means that the optimization task can be expressed in a so-called nested formulation where the equilibrium constraint is taken care of by the state function formulation

$$\begin{cases} \min x & f(x) \\ \text{subject to} & g(u(x)) \leq 0 \end{cases} \tag{3}$$

The optimization task presented in equation (1) is called simultaneous formulation in comparison. Equation (3) is usually solved by evaluating derivatives of f and g with respect to x.

IV. TOPOLOGY OPTIMIZATION OF VEHICLE

A. Geometric Modeling

The different steps have been taken during the current component development process are explained with respect to hull structure of wheeled combat vehicle as shown in Figure 1. There are various types of component developments processes going on depending on project and application.

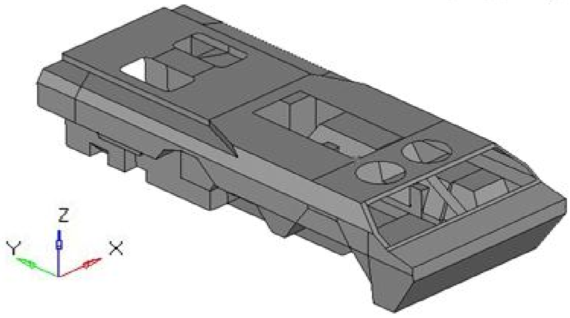

Figure 1. Isometric view of model.

Vehicle dimensions are length=6.3m, Breadth=2.5m, Height=1.8m and total payload of vehicle consisting of self-weight and external load= 13.5 ton. Loading conditions were extended to the 3g case for safe design. Material properties are given in Table 1.

Yield Stress (σ_Y)	750 MPa
Tensile Strength	1100 MPa
Modulus of Elasticity	210 GPa
Mass Density (ρ)	7800 kg/m^3
Poisson's Ratio (ν)	0.3

Table 1. Material properties.

B. Meshing scheme

It is very important to establish the finite element model for a complex structure. The model not only affects the analysis process, but also influences the reliability of the results. This work is done by Altair, the finite element pre-processor used in this work is HyperMesh. HyperMesh is easy to learn and has an interface environment integrated with Optistruct [5,6]. Mesh Convergence study has been done two get proper results. Meshed model of vehicle is shown in Figure 2 and details of meshing are given in Table 2.

Mesh Type (2D)	Element Size	No. of Elements	No. of Nodes
Mixed	10 mm	255699	255977

Table 2. Meshing details.

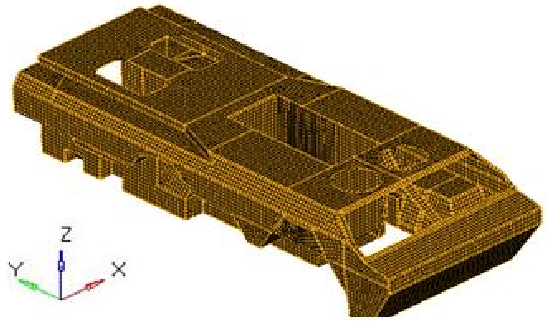

Figure 2. Meshed model.

C. Performing Topology Optimization

A detailed topology optimization study was carried out on the existing design to realize the critical load paths and thereby obtain an insight on the optimal configuration. This is achieved through the use of a density function based on load distribution over the finite elements by using optimization parameters given in Table 3.

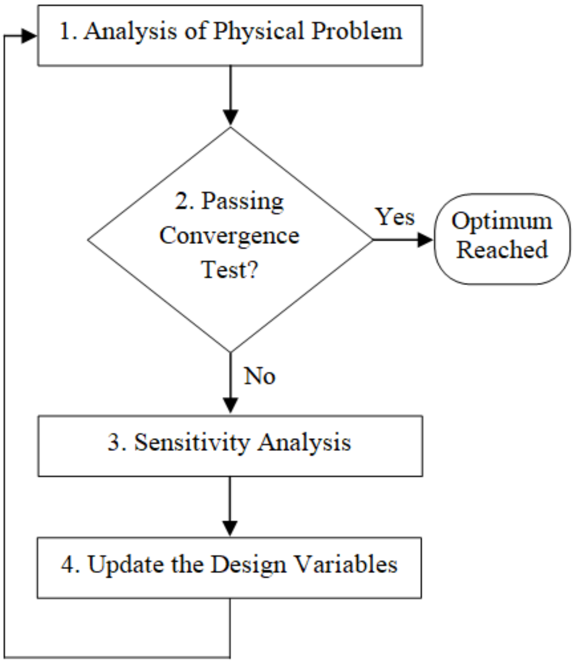

Figure 3. The iterative process used in OptiStruct.

Objective function	Minimize Compliance
Design variable	Element density
State constraint	
Volume fraction 0.3	
Response	Compliance and total
volume	

Table 3. Topology optimization parameters [7].

OptiStruct has the advantage of being capable to solve the major kinds of optimization problems. It is able to solve problems with millions of design variables, which this research will be dealing with. The iterative workflow can be seen in Figure 3.

V. OPTIMIZATION RESULTS AND DISCUSSION

The topology optimization nephogram and iso surface of topology are shown in Figure 4 and Figure 5 respectively. Although the result of optimization is rough comparatively, it still can be seen that the basic shape profile consistent with the traditional design, the link between the objective function compliance and the number of iterations shown in Figure 6.

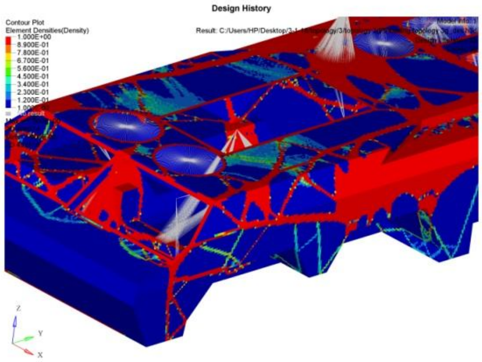

Figure 4. Topology optimization nephogram of hull structure.

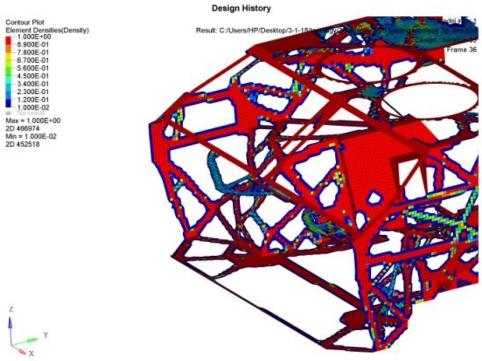

Figure 5. Iso surface of topology optimization.

The surfaces of the resulting beams are uneven because of the limitation given by the element mesh. Also, it could see irrational how some beams are crooked. However, the load paths are, after some iterative steps, relatively clear and easy for an engineer to understand. It is in the nature of topology optimization that the resulting structure is exposed to tension and compression. With a minimum exposure to bending and torsion, along with the manufacturing constraints (MINDIM), it is hence most natural that the beams are circular.

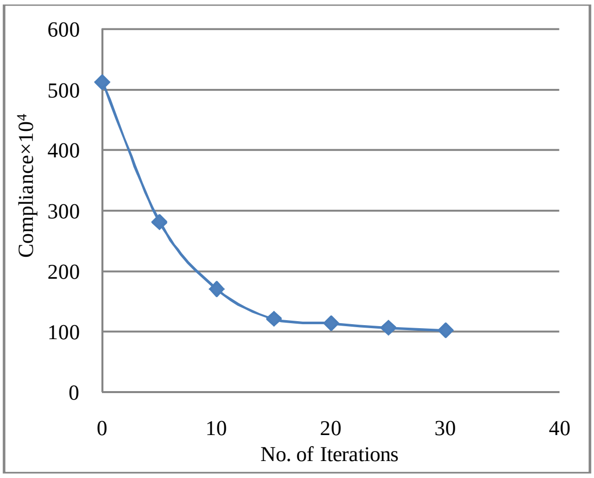

Figure 6. Convergence curve.

CONCLUSION

- A recommendation is made to present topology optimization at early stage where the big decisions are made where design concepts and load paths are more valuable than a detailed design.
- Topology optimization should be done parallel to the design during development of a vehicle. It is a powerful tool to use for giving input to designers. Topology optimization is best to use in the early phase of design where knowledge of the structure is low and the design freedom is high.
- By applying topology optimization early, great knowledge of the load paths and weaknesses in the structure are received early and will help the designer to make good decisions.
- To use topology optimization as a tool for material placement is more systematic than to use more or less guesses based on experience. This is especially true for such a complex structure that is investigated in this project.

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